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The role of morphology on the displacement of particles in a step–pool river system

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Abstract

Although studies of sediment transport in steep and coarse-grained channels have been more numerous in recent years, the dynamics of sediment transport in step–pool river systems remain poorly understood. This paper investigates displacements of individual clasts through Spruce Creek (Québec, Canada), a classic step–pool channel, and the effects of the channel morphology on the path length of the clasts. Passive integrated transponder tags (PIT) were used to track the displacement of 196 individual particles over a range of discharges including the bankfull stage. Clasts were tracked after five sequences of flood events. The results showed that the distance distributions match a two-parameter Gamma model. Equal mobility transport occurs for the particle size investigated during each sequence of flood events. Mean travel distance of the clasts can be estimated from excess stream power, and the mobility of the clasts is more than an order of magnitude less than the model reported in riffle–pool channels. The dominant morphological length scale of the bed also controls the path length of the clasts. These results confirm some preliminary observations on sediment transport in step–pool channels.

Keywords: Gravel-bed rivers; Step–pool; Passive integrated transponders; Radio frequency identification; Sediment transport; Particle mobility; Distance of movement; Bed morphology; Steep channels

1. Introduction

Step–pool channels occur in a wide range of bioclimatic environments (Bowman, 1977), from arid (Wohl and Grodek, 1994) to humid forested areas (Heede, 1972). They are commonly found in steep headwater mountain streams, where the channel width to depth ratio is small, bed material is heterogeneous, and slopes exceed 4 to 7% (Chin, 1989; Grant et al., 1990; Grant and Mizuyama, 1991). The longitudinal profile of step–pool channel is characterized by steps viewed as congested zones where clasts have clustered (Church and Jones, 1982; Church et al., 1998). The steps are generally composed of an accumulation of cobbles and boulders that are transverse or oblique to the channel (Zimmermann and Church, 2001; Chin and Wohl, 2005) and their occurrence depends on the local availability of keystones that remain immobile on the contemporary flow regime (Church and Zimmermann, 2007). Steps define breaks of slope and alternate with pools, containing finer bed material.

The geometry of step–pools is defined by step spacing (L) and step height (H) and their ratio has been found to fall in the range $0.06 \leq H/L \leq 0.20$, which corresponds to the range of gradients where step–pools are found (Chin and Wohl, 2005; Church and Zimmermann, 2007). Step spacing has also been correlated with overall stream gradient (S) in the form $H/L \alpha S^{\beta}$, in which $0.42 \leq \beta \leq 0.68$ (Abrahams et al., 1995). Chartrand and Whiting (2000) have shown that the step spacing was 0.6 time the channel width (W), while Bowman (1977) reported a spacing of $1.4W$. Chin (1989) obtained a spacing of $2.7W$ for step–pools in Santa Monica Mountains (Colorado). Data from numerous locations have shown that step–pool spacing is usually less than one to four channel widths.

The step–pool morphology serves a fundamental role in river systems controlling hydraulic resistance (Wohl and Grodek, 1994; Abrahams et al., 1995) and energy dissipation (Hayward,

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1980; Whittaker and Jaeggi, 1982). They are characterized by relative submergence of the large clasts (Y/d_{84}) that is <1.2 (Bathurst, 1978), where Y is the flow depth and d_{84} the 84th percentile bed material size. At high flow stage, water flows over and in between the large roughness elements that form the steps and plunge into the pools below, promoting a tumbling highly turbulent flow (Peterson and Mohanty, 1960; Whittaker, 1987). The available energy is dissipated by eddies (Wohl and Thompson, 2000). Therefore, the potential energy available for erosion and sediment transport at high stage is reduced by the steps (Chin, 2003).

In their recently published review of empirical research on step–pool channels, Chin and Wohl (2005) pointed out some of the common observations on bedload transport in these systems: transported sediment is derived from localized sites on adjacent hillslopes and in the channel; bedload entrainment and transport are spatially and temporally discontinuous (Ergenzinger and Schmidt, 1990); sediment are preferentially stored in and mobilized from pools (Schmidt and Ergenzinger, 1992; Marion and Weirich, 1999); bedload transport during lower flows tends to be characterized by equal-mobility transport (Blizard and Wohl, 1998; Marion and Weirich, 2003) where larger grains are as easily entrained as smaller ones because they are more exposed to lift and drag forces (Parker et al., 1982). In spite of these findings, there is still a paucity of field data on the displacement of clasts in step–pool channels. Such data are a good indicator of bedload transport response of the stream to a given water discharge and to sediment supply conditions, and are critical for understanding of the development of channel morphology (see Haschenburger and Church, 1998; Sear et al., 2000).

Morphological features of step–pool channels should play a significant role on the distance of displacement of the bed material. At this time, it is still not possible to predict sediment transport rates in step–pool systems as a function of flow and in-channel sediment storage (Church and Zimmermann, 2007). It

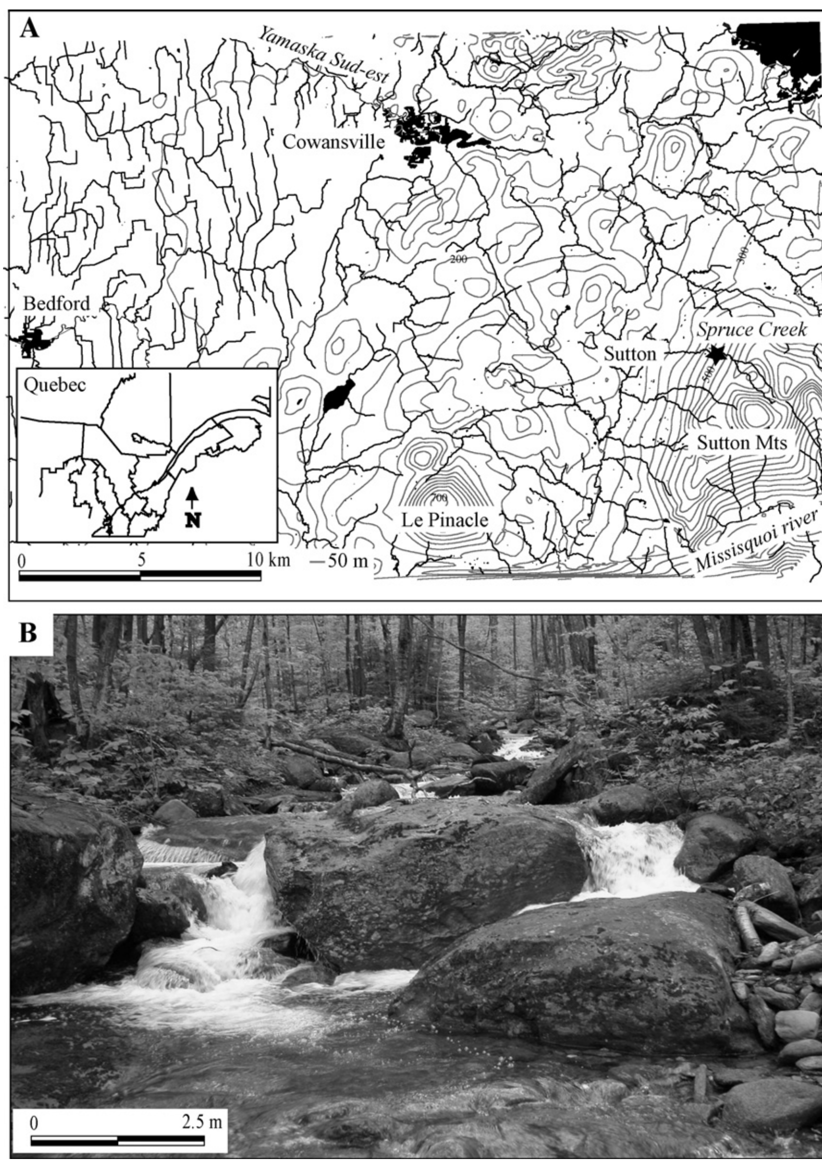

Fig. 1. Location (A) and upstream view (B) of Spruce Ck step–pool channel.